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# RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF HELMHOLTZ RESONATORS

FOR DAMPING PRESSURE FLUCTUATIONS IN 3.6-INCH

RAM JET AT MACH NUMBER 1.90

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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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## SUMMARY

A preliminary investigation has been conducted at a Mach number of 1.90 to determine if Helmholtz resonators can be used in a typical ram-jet configuration to damp pressure pulsations associated with shock oscillations.

One of the two resonators effectively damped pressure pulsations that occurred when the ram jet was operating in the vicinity of its peak pressure recovery. This damping resulted in an increase in total-pressure recovery of 4 percent and considerably reduced the movement of the shock at the diffuser inlet. Neither resonator was effective in damping the pressure pulsations over the entire range of ram-jet operating conditions.

## INTRODUCTION

Ram jets operating at mass-flow ratios below that of peak pressure recovery often exhibit unsteady flow phenomena. This condition (commonly referred to as buzz) is characterized by shock oscillations and by pressure pulsations of the air flowing through the unit.

Several investigators have reported on the characteristics of buzzing ram jets (for example, references 1 to 3). Reference 1 indicates that the frequency of the shock oscillation and pressure pulsations may be calculated theoretically by an analogy to the acoustic properties of a classical Helmholtz resonator. The experimental data of reference 1 show good correlation with theoretically predicted frequencies.

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Elimination of the pressure pulsations would extend the range of stable operation of supersonic diffusers. Several members of the NACA Lewis laboratory have suggested for this purpose the addition of a Helmholtz-type resonator upstream of the combustion chamber. This report presents the results of a preliminary experimental investigation conducted in the 18- by 18-inch supersonic tunnel (Mach number, 1.90) of the Lewis laboratory to establish: (a) whether the addition of a resonator would prevent the occurrence of the buzz phenomenon in a typical supersonic diffuser under any operating condition; (b) the effect, if any, of the resonator on the performance characteristics of the diffuser. In addition, the investigation provides a further correlation of experimental and theoretical buzz frequencies. The scope of the investigation was confined to the effects of two specific resonators.

### SYMBOLS

The following symbols are used in this report:

- A area
- $A_0$  area of diffuser inlet with spike removed
- c velocity of sound
- f frequency
- L length of neck of resonator
- $l$  effective length of resonator neck used in calculating ram-jet buzz frequencies (equation (3))
- M Mach number
- m mass-flow rate
- P total pressure
- S area of neck of resonator
- V volume of resonator cavity
- $v$  effective resonator volume used in calculating ram-jet buzz frequencies (equation (3))
- $\gamma$  ratio of specific heats of air

## Subscripts:

- 0 free-stream conditions
- 1 diffuser inlet
- 2 combustion-chamber inlet
- 3 ram-jet outlet

## THEORY

Characteristics of a Helmholtz resonator. - The properties of a Helmholtz resonator of the type shown schematically in figure 1 can be found in any standard text on sound (for example, reference 4). An expression for the natural frequency of an ideal resonator is

$$f_n = \frac{c}{2\pi} \sqrt{\frac{S}{VL}} \quad (1)$$

If a correction for the open end of the neck is introduced, equation (1) becomes

$$f_n = \frac{c}{2\pi} \sqrt{\frac{S}{V \left( L + \frac{1}{2} \sqrt{\pi S} \right)}} \quad (2)$$

An example of the use of a Helmholtz resonator to attenuate sound waves of a given frequency is reported in reference 4. As shown schematically in figure 2, a sound wave introduced into a channel at A is prevented from continuing along the passage beyond B by the presence of a resonator BC tuned to the frequency of the forced vibration at A.

When applied to a ram-jet configuration, it was intended that the presence of a resonator (tuned to the natural frequency of the air mass flowing through the unit) would attenuate in whole or in part the pressure pulsations associated with buzz. It is noted, however, that the extension of a theory developed for acoustical vibrations to pressure disturbances of large amplitude is subject to some error due to the finite strength of the disturbances.

The mechanism of absorption of energy by a resonator is not well understood. One theory is that the damping of a pressure pulsation by means of a tuned Helmholtz resonator is accomplished by a dissipation of the pulse energy into thermal energy by friction within the neck of the resonator. According to the simple theory represented by equation (1), a tuned resonator may have any dimensions so long as the ratio  $S/LV$  is held constant. Relations developed in reference 5, however, indicate that the efficiency of energy absorption is dependent on the size of the resonator. No attempt was made in the present investigation to determine this optimum size.

Prediction of resonant frequency of a ram-jet configuration. - The method of reference 1 gives the following approximate equation for the determination of the buzz frequency of an isolated ram-jet configuration:

$$f_{\text{theor}} = \frac{c}{2\pi} \sqrt{\frac{A_1}{2v} \left\{ 1 - \frac{\gamma+1}{2} A_2 \frac{M_2 P_0}{c} \frac{d \frac{P}{P_0}}{d m_2} - v A_1 \frac{P_0^2 \left[ \frac{d \frac{P}{P_0}}{d m_2} - \frac{\gamma-1}{2} \frac{1}{v} \frac{A_2}{A_1} \frac{c M_2}{P_0} \right]^2}{4 c^2 l} \right\}} \quad (3)$$

The values of  $l$ ,  $v$ ,  $A_1$ , and  $A_2$  used in equation (3) are determined by the geometry of the ram-jet configuration. This equation is applicable when the slope of the curve of combustion-chamber total pressure as a function of diffuser mass-flow rate is greater than or equal to zero.

#### APPARATUS AND PROCEDURE

This investigation was conducted in the Lewis 18- by 18-inch supersonic tunnel. From a previous calibration, the test-section Mach number in the vicinity of the inlet was determined to be 1.90 with a maximum variation of  $\pm 0.01$ . Inlet total pressures slightly below atmospheric and inlet stagnation temperatures of approximately 150° F were maintained during all runs.

The ram-jet configuration used in this investigation (fig. 3) is the same as that used in reference 6. A projecting central body designed to produce nearly isentropic supersonic diffusion was utilized to compress the air ahead of the inlet.

2128 A photograph of the two resonators used in this investigation is shown in figure 4. The large resonator had a neck of  $1\frac{1}{4}$ -inch inside diameter and was 15 inches long. An 8-inch-inside-diameter pipe fitted with a movable piston with a maximum piston travel of 22 inches comprised the resonator cavity. The small resonator had a  $7/16$ -inch-inside-diameter neck 15.3 inches long. The resonator cavity consisted of a  $3\frac{3}{4}$ -inch-inside-diameter pipe fitted with a movable piston having a travel of 20 inches. Both resonators were designed to be tunable to frequencies as low as 20 cycles per second, as determined from equation (2). During test runs the resonators were connected to the subsonic diffuser 3 inches upstream of the combustion-chamber inlet. The resonator necks were run through the upper tunnel wall and the resonator cavities were mounted outside the tunnel.

Instantaneous static-pressure measurements were taken in the combustion chamber and recorded by means of a diaphragm-type pressure pickup fed through an amplifier to a magnetic-pen motor and recorder. Static and total pressures of the air entering the combustion chamber were determined by means of a 40-pitot-static-tube rake arranged in eight symmetrically located radial rows.

Observations of the air flow in the vicinity of the inlet were made visually by means of a two-mirror schlieren system. High-speed schlieren pictures were taken at significant data points with a 16-millimeter movie camera running at approximately 2000 frames per second.

Pressure-recovery characteristics of the ram-jet configuration were determined at various outlet-plug settings for the ram jet alone and for the ram jet with each of the two resonators. For outlet-plug settings at which buzz occurred, the effectiveness of the resonators in damping the pressure pulsations was checked by varying the resonator volume with the piston. The configuration buzzed at all outlet-inlet area ratios  $A_3/A_0$  below 0.615, which corresponds to peak pressure recovery. This fact was verified by schlieren observation and by the record of the instantaneous pressure pickup.

## RESULTS AND DISCUSSION

### Instantaneous Pressure Measurements

Reproductions of the traces of instantaneous pressure measurements of the static pressure in the combustion chamber taken at significant data points are shown in figure 5. Included with each trace is the

information concerning configuration, area ratio  $A_3/A_0$  and resonator condition. The theoretical frequency indicated is the value computed from equation (2).

Figure 5(a) is a trace taken with the ram jet alone, whereas figures 5(b) and 5(c) were taken with the 8-inch and  $3\frac{3}{4}$ -inch resonators installed. In figures 5(b) and 5(c) the piston is at or near the bottom (zero volume) of the resonator cavity. These traces show the type of pulsing occurring at ram-jet area ratios slightly below peak recovery. If the frequency is calculated by counting the total number of pulses without regard to amplitude, the buzz frequency is 34 cycles per second. The frequency of the large amplitude oscillation is between 19 and 20 cycles per second. The similarity of the wave forms in these three traces indicates that the effect of the neck of either resonator is small when the piston is at or near its bottom position.

A comparison of figures 5(d) and 5(c) illustrates the most significant result of the investigation. In figure 5(d) the volume of the  $3\frac{3}{4}$ -inch resonator cavity has been increased to correspond to a theoretical frequency of 48 cycles per second. The large amplitude pulse has been completely damped out, leaving only a very small amplitude pulse with a frequency of 53 cycles per second. Movement of the piston showed that damping persisted over a band of theoretical resonator frequencies ranging from 43 to 64 cycles per second. Buzzing reoccurred at resonator volumes corresponding to theoretical frequencies above or below these values. The  $3\frac{3}{4}$ -inch resonator did not damp the pulsations at area ratios except those immediately below peak recovery, nor did it show any effect on the wave form at the other area ratios where it was not effective in damping.

Figure 5(e) is typical of the type of pulsing encountered with all configurations for area ratios below approximately 0.500, which for this curve was obtained with the 8-inch resonator installed. In this range of area ratios, the pulsing has changed to one of a regular sinusoidal nature, with little change in frequency and amplitude for values of  $A_3/A_0$  less than 0.500.

Increasing the volume of the 8-inch resonator produces a marked change in the type of pulsing, as shown in figure 5(f). A comparison of figures 5(f) and 5(e) illustrates the drastic change in wave form and a reduction in frequency from 41 to 11 cycles per second. The effect has been to couple the effective volume of the air in the ram jet with that in the resonator. Equation (3) shows that an effective



increase in  $v$  would lower the resonant frequency of the ram-jet resonator combination. This lowering of the resonant frequency and change of wave form was noted over the entire range of area ratios for which buzzing occurred.

### Shock Oscillation

The chronologically arranged selected frames from high-speed schlieren pictures shown in figures 6(a) and 6(b) correspond to the conditions of figures 5(c) and 5(d), respectively. The photographs of figure 6(a) correspond to the changes in flow pattern occurring during one large oscillation followed by one small oscillation, as shown in the trace of figure 5(c). The photographs of 6(b) correspond to a single oscillation of figure 5(d). Along with the damping of the pressure pulsations, the effect of the resonator has been to change the mode of oscillation of the bow wave. Before damping (fig. 6(a)) the shock alternately oscillates on the spike and then with a larger amplitude completely off the spike into the free stream. In the damped condition (fig. 6(b)) the shock still oscillates with a low amplitude and remains on the spike at all times.

### Diffuser Pressure Recovery

The effect of the resonators on the pressure recovery of the diffuser is shown in figure 7. All data points except those indicated by arrows correspond to minimum resonator volume. Damping of the pressure pulsations by the  $3\frac{3}{4}$ -inch resonator increased the diffuser pressure recovery 4 percent, as indicated by the tailed square symbol at an area ratio  $A_3/A_0$  of 0.555. At  $A_3/A_0$  of 0.430, increasing the volume of the 8-inch resonator first decreased the diffuser pressure recovery slightly, then increased it to a value approximately 2 percent higher than the pressure recovery for the zero-volume condition. The 8-inch resonator similarly affected the pressure recovery for all area ratios at which buzz occurred.

### Variation of Pulse Strength

The variation of pulse strength with area ratio is shown in figure 8. Pulse strength is defined as the difference between maximum and minimum instantaneous pressures. The pulse strength remained relatively unchanged from a point slightly below the area ratio for peak pressure recovery to the fully closed position ( $A_3/A_0 = 0$ ).

For the diffuser alone and the diffuser with the 8-inch resonator at zero volume, this value was equal to 5.7 pounds per square inch; for the diffuser with the  $3\frac{3}{4}$ -inch resonator at minimum volume, the value was equal to 3.4 pounds per square inch. This apparent discrepancy is believed to result from the fact that the  $3\frac{3}{4}$ -inch resonator did not operate at zero volume due to an obstruction to the movement of the piston. The effect of the nonzero volume seems to have been to reduce the strength of the pulse without affecting its form (fig. 5(c)). The tailed square symbol at an area ratio of 0.555 indicates the large decrease in pulse strength from a value of 3.6 to 0.5 pounds per square inch when the resonator was effective in damping the pulsations.

#### Correlation of Theoretical and Experimental Buzz Frequencies

A determination of theoretical ram-jet buzz frequencies requires a knowledge of the variation of diffuser pressure recovery with diffuser mass-flow rate. A plot of these data for the configuration investigated is presented in figure 9. Experimental buzz frequencies as a function of area ratio are presented in figure 10. Included in figure 10 is a theoretical curve giving the estimated buzz frequency for the data points of figure 9 as calculated from equation (3). The maximum theoretical frequency corresponding to  $\frac{dP_2/P_0}{dm_2} = 0$  was calculated to be 45.3 cycles per second. Experimental values of buzz frequencies for area ratios at which the slope  $\frac{dP_2/P_0}{dm_2}$  was approximately zero ranged from 44 to 54 cycles per second. At values of the area ratio where the slope  $\frac{dP_2/P_0}{dm_2}$  was positive, the trend of the experimental data shows close agreement with the theoretical curve. This correlation between experimental and theoretical buzz frequencies appears to verify the use of equation (3) for approximate prediction of the buzz frequencies of a ram-jet configuration.

#### CONCLUDING REMARKS

The experimental results of this investigation have shown that the  $3\frac{3}{4}$ -inch resonator effectively damped pressure pulsations associated with the buzz phenomenon for a very narrow range of operating conditions. Damping the pressure pulsations resulted in a 4-percent increase in

diffuser pressure recovery. Neither resonator damped the pulsations over the complete range of operating conditions, which may be due to the dependence of the efficiency of a resonator on its geometry. No attempt has been made to determine optimum resonator dimensions in this investigation.

When the  $3\frac{3}{4}$ -inch resonator was effective in damping pressure pulsations, it was tuned for a range of theoretical frequencies from 43 to 64 cycles per second. The pulse frequency before damping, calculated without regard to the amplitude of adjacent pulses, was 34 cycles per second. Viscous effects in the neck and possible leakage past the piston, which would effectively lower the estimated theoretical frequency of the resonator, may account for this discrepancy. Estimation of the magnitude of these effects was not possible.

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Cleveland, Ohio.

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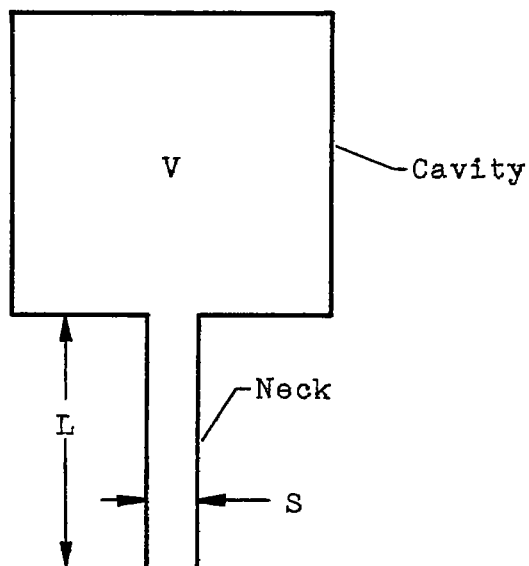


Figure 1. - Helmholtz resonator.

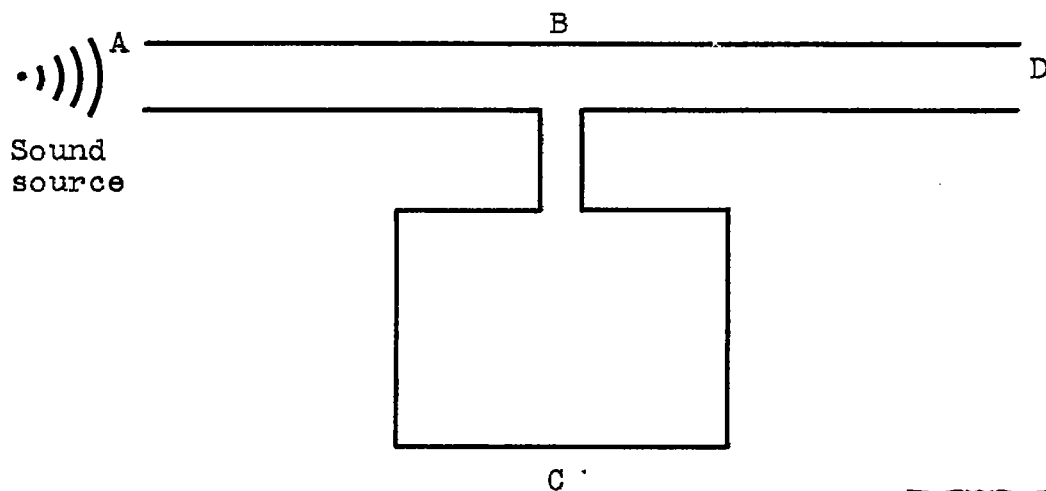


Figure 2. - Sound absorption by Helmholtz resonator.

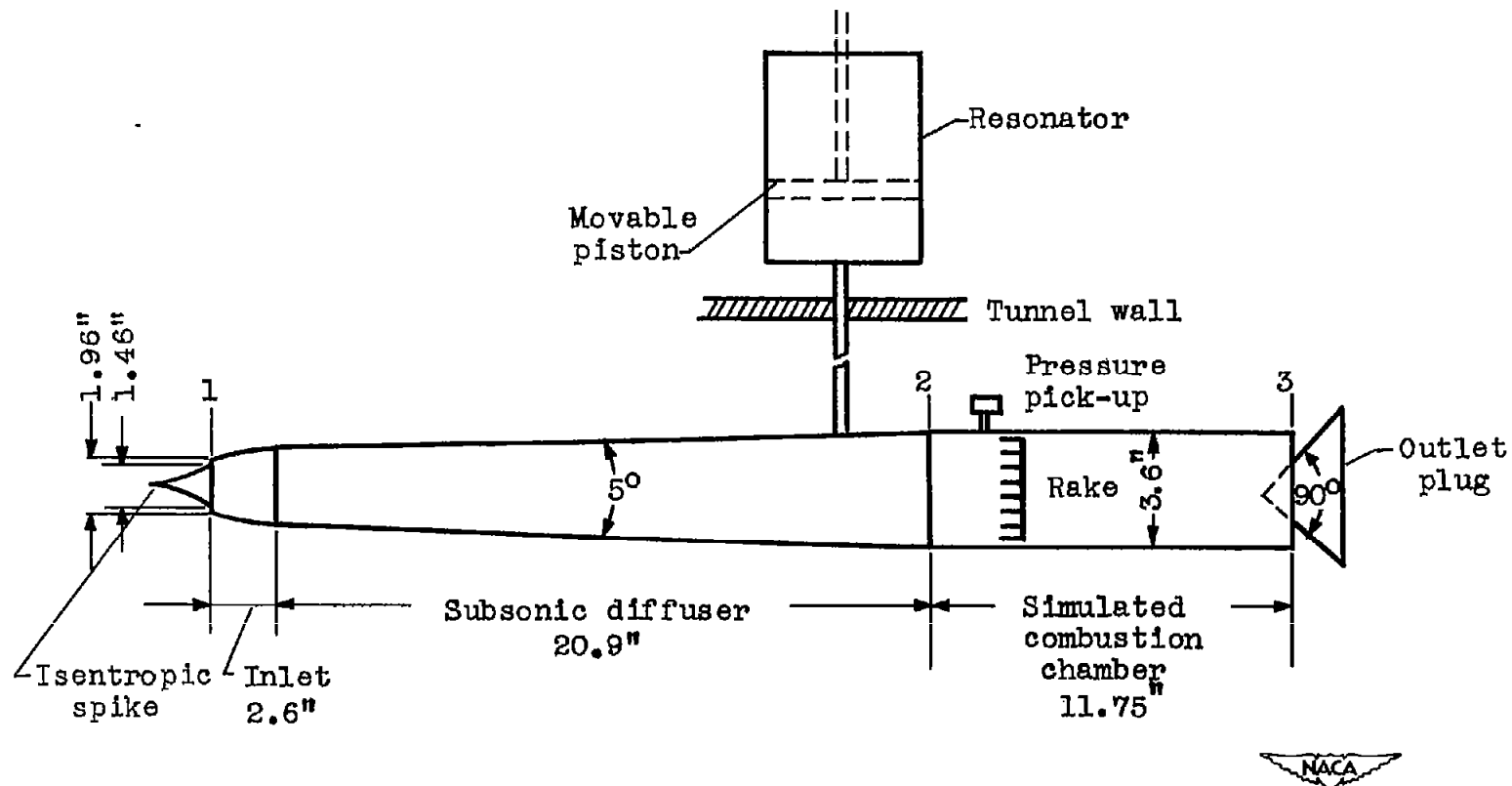


Figure 3. - Schematic diagram of configuration investigated.

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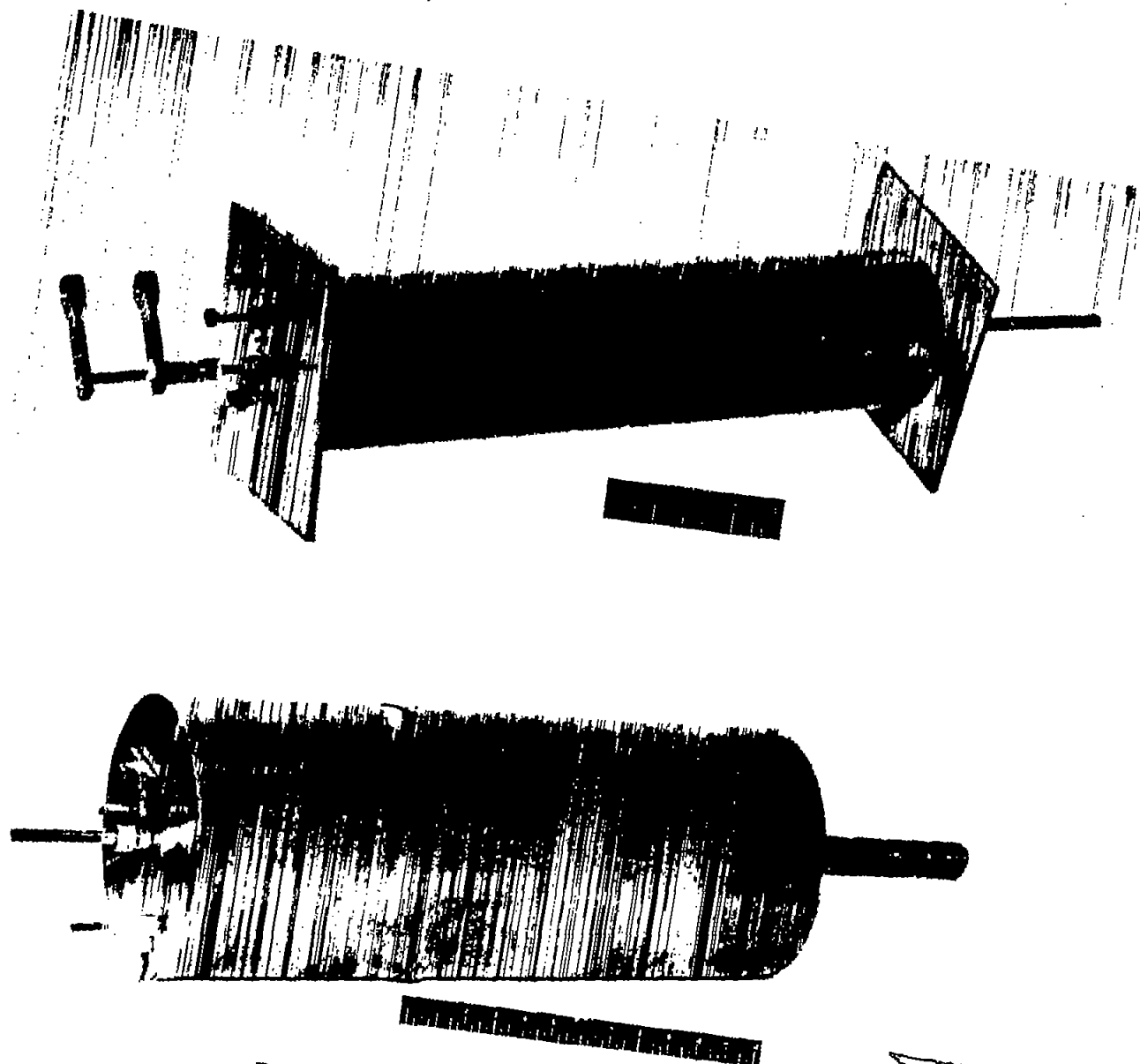
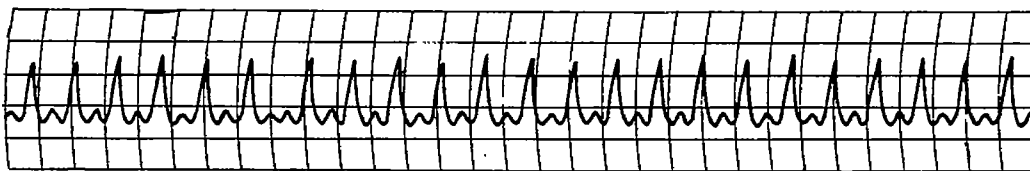


Figure 4. - Resonators used in investigation.

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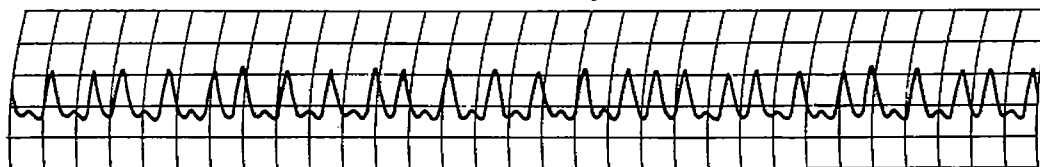
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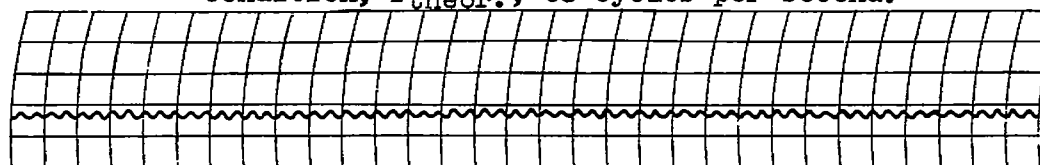
(a) Diffuser, no resonator;  $A_3/A_0$ , 0.555.



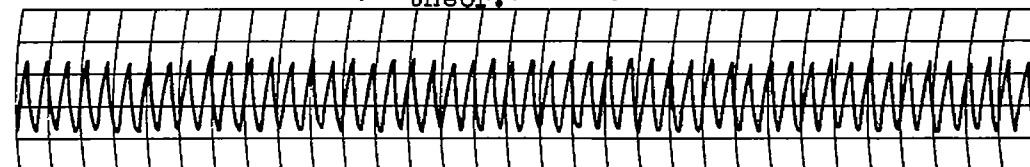
(b) Diffuser with 8-inch resonator;  $A_3/A_0$ , 0.555; resonator condition, 0 volume.



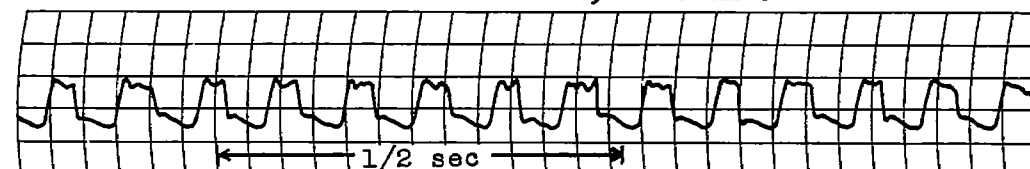
(c) Diffuser with  $3\frac{3}{4}$ -inch resonator;  $A_3/A_0$ , 0.555; resonator condition,  $f_{\text{theor.}}$ , 68 cycles per second.



(d) Diffuser with  $3\frac{3}{4}$ -inch resonator;  $A_3/A_0$ , 0.555; resonator condition,  $f_{\text{theor.}}$ , 48 cycles per second.



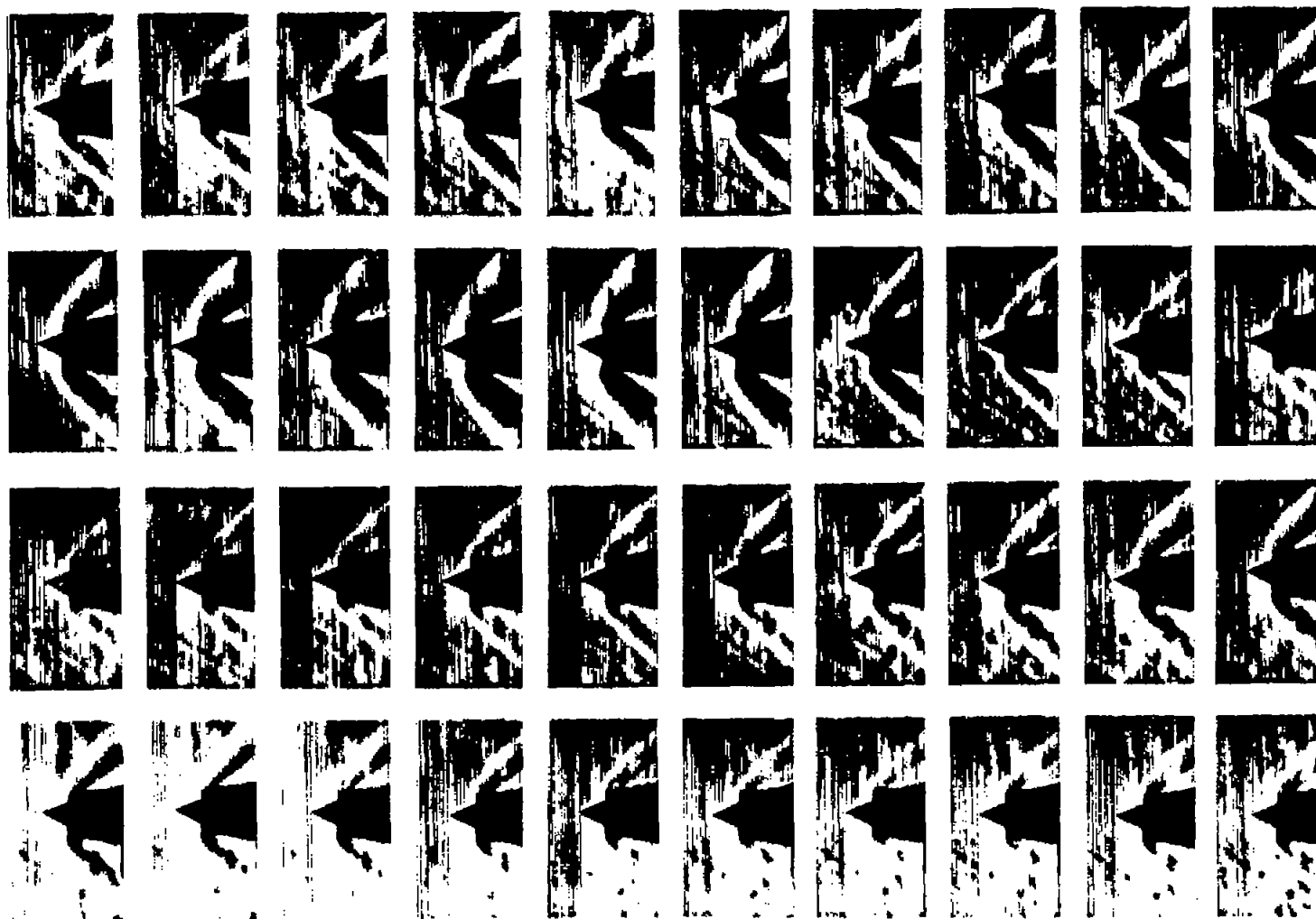
(e) Diffuser with 8-inch resonator;  $A_3/A_0$ , 0.430; resonator condition, 0 volume.



(f) Diffuser with 8-inch resonator;  $A_3/A_0$ , 0.430; resonator condition,  $f_{\text{theor.}}$ , 20 cycles per second.



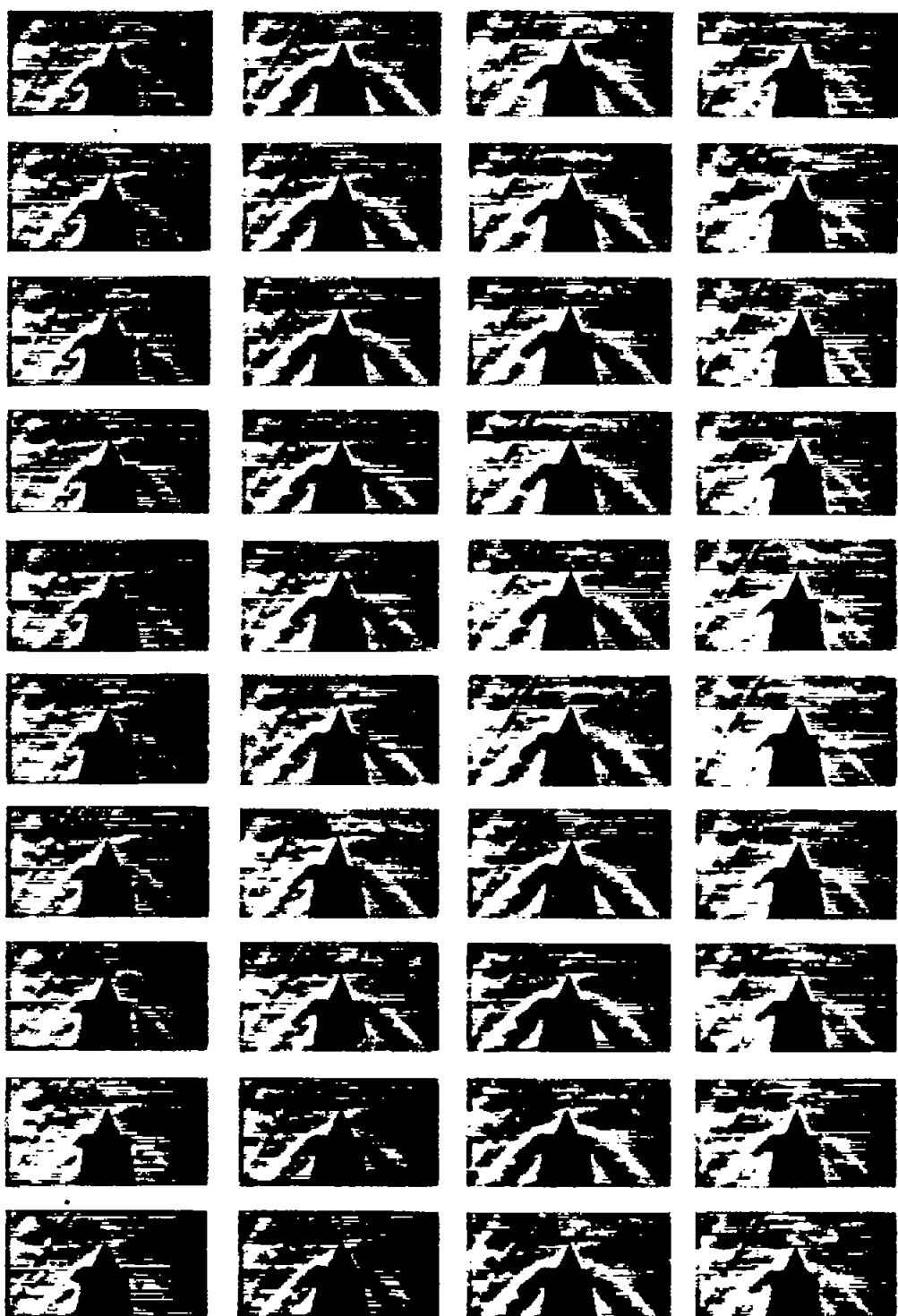
Figure 5. - Typical instantaneous pressure measurements.



(a) Diffuser with  $3\frac{3}{4}$ -inch resonator;  $A_3/A_0, 0.555$ ; resonator condition,  $f_{\text{theor}}$ , 68 cycles per second.

Figure 6. - High-speed schlieren photographs of shock oscillation.





(b) Diffuser with  $\frac{3}{4}$  inch resonator;  $A_2/A_0, 0.555$ ; resonator condition,  $f_{thor} = 48$  cycles per second.

Figure 6. - Continued. High-speed schlieren photographs of shock oscillation.



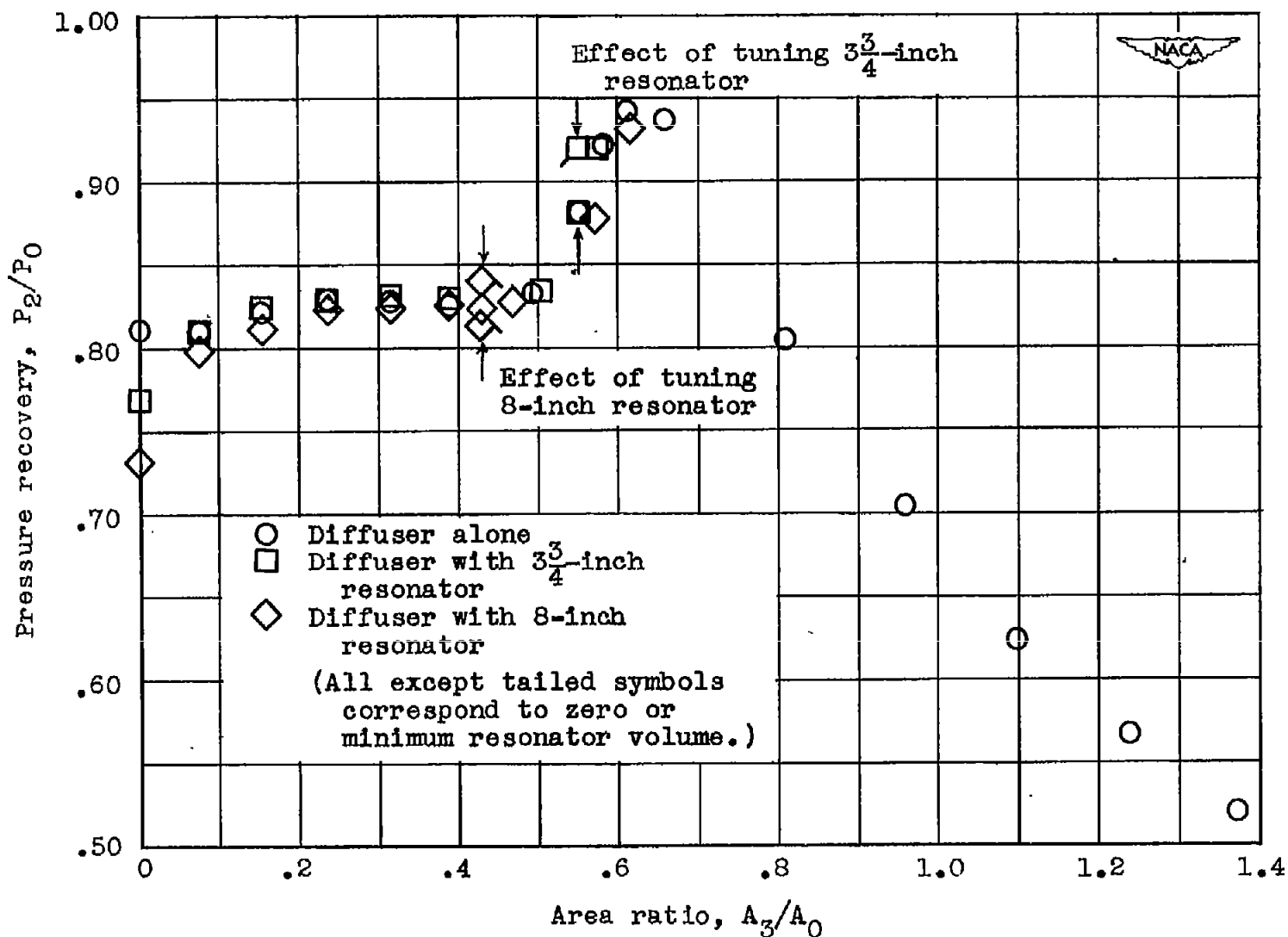


Figure 7. - Pressure-recovery characteristics of configurations investigated.

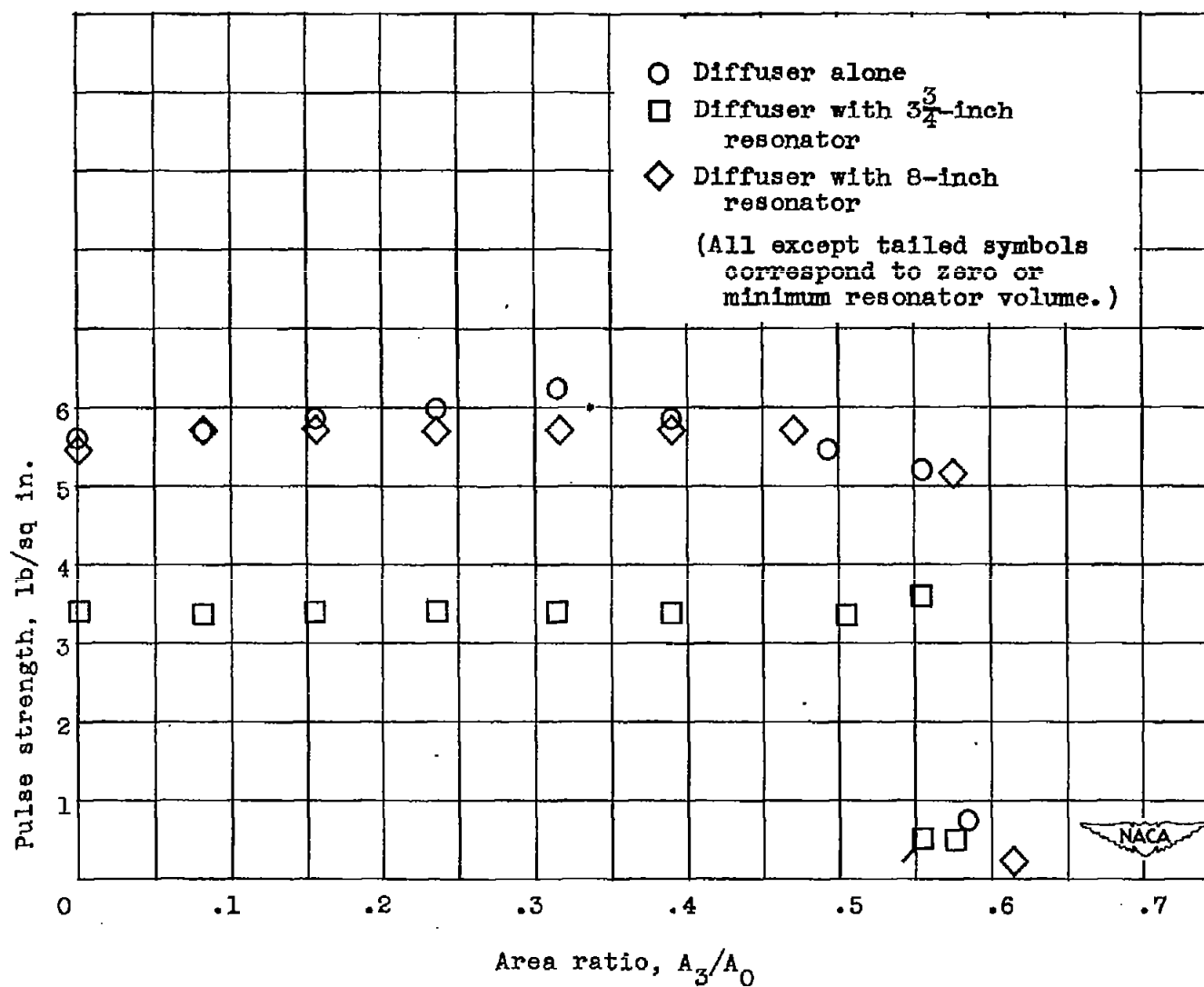


Figure 8. - Variation of pulse strength with area ratio.

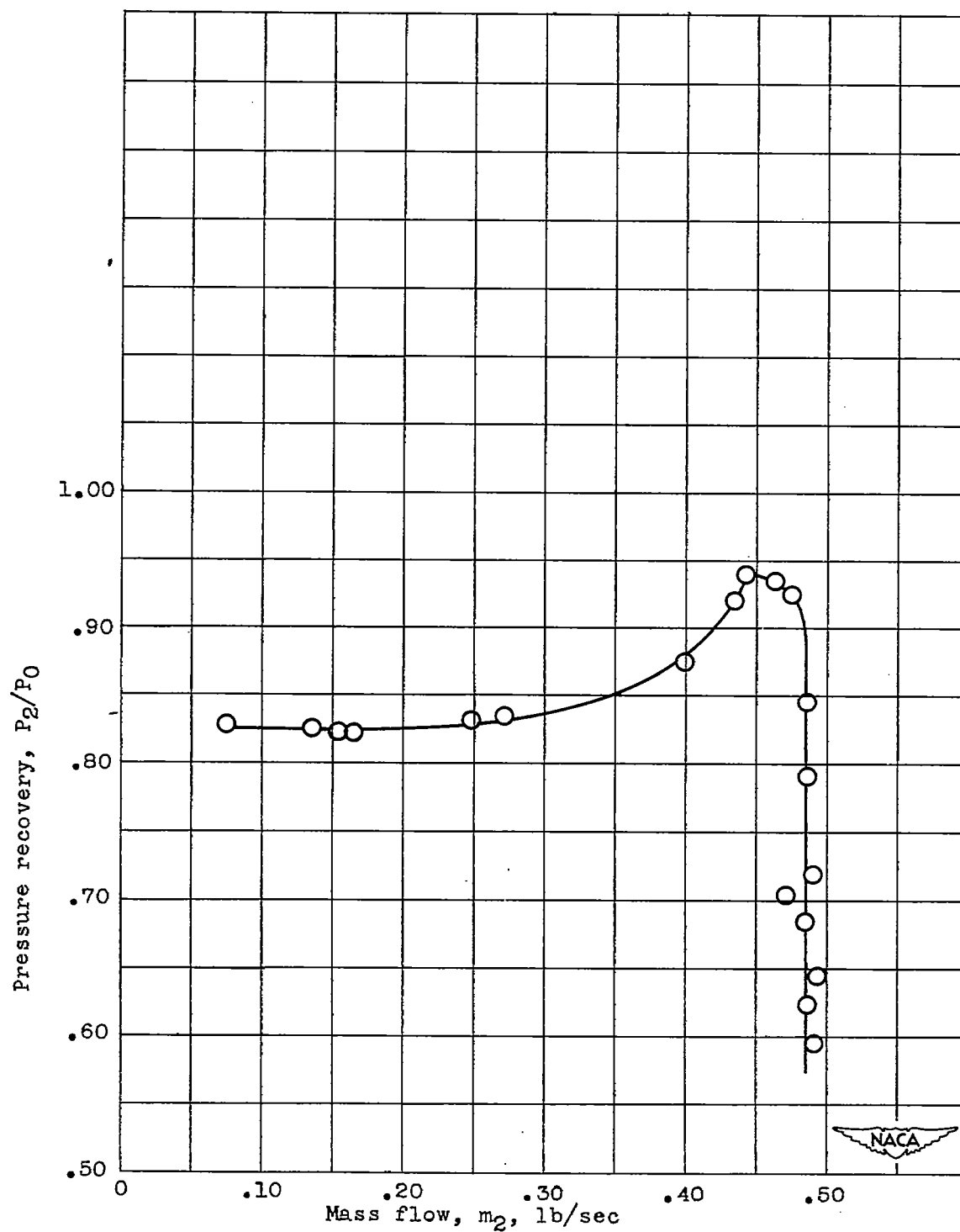


Figure 9. - Variation of diffuser pressure recovery with mass flow.

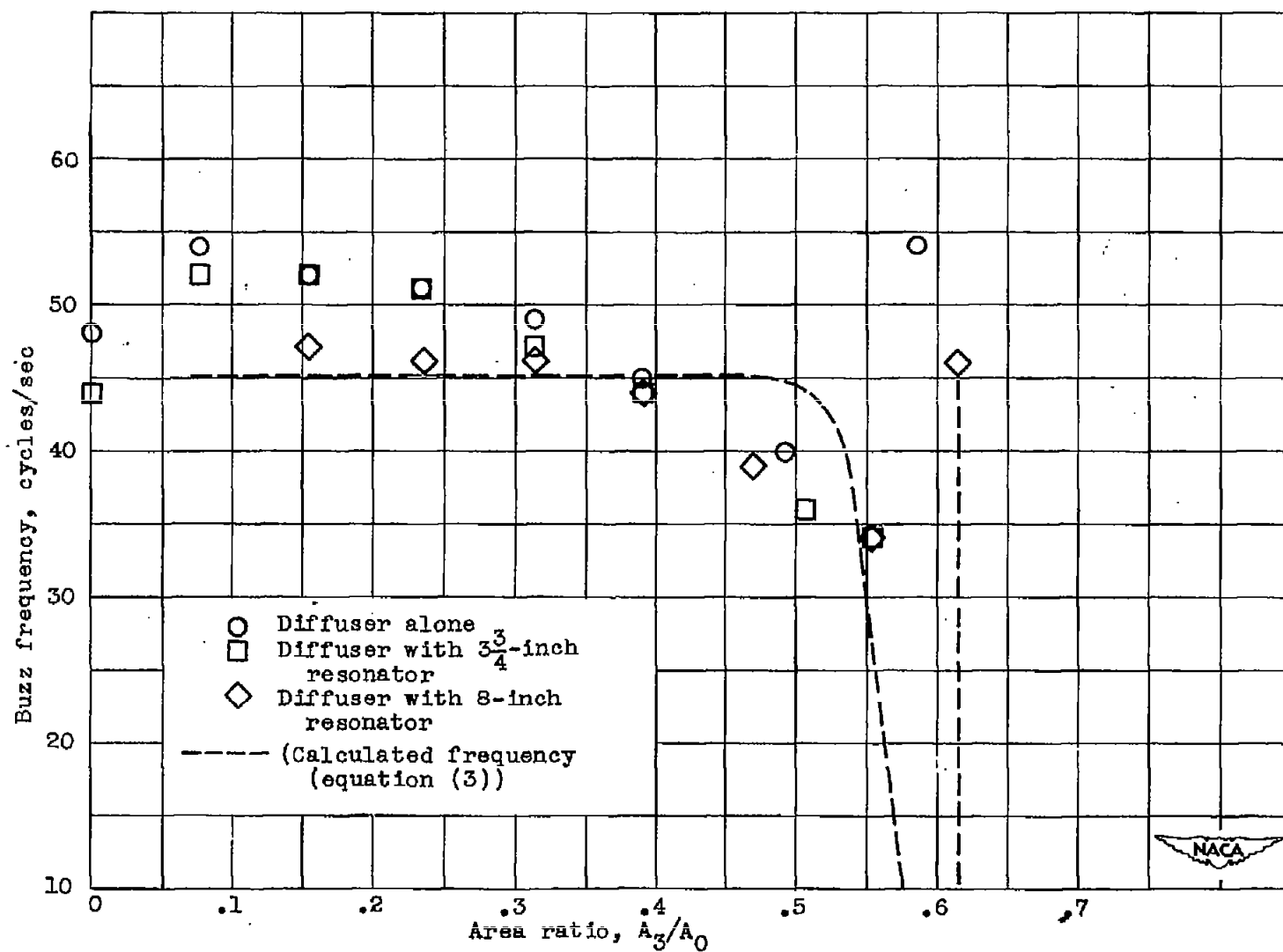


Figure 10. - Variation of buzz frequency with area ratio.